Linux on Open Source Hardware

Linux at Fermilab Quarterly meeting

Feb 24, 2016

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Embedded Systems Engineer, **OSH Park**

“Perfect Purple PCBs”

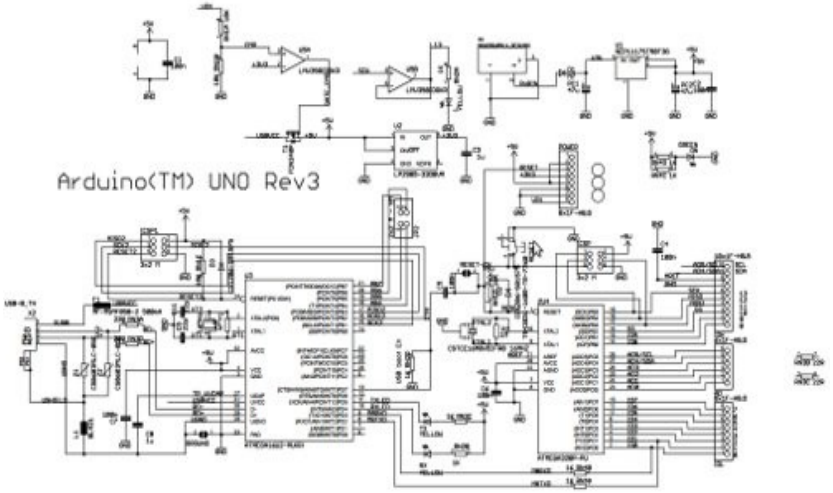
Open Source Hardware

Design is made
publicly available
so that anyone can
study,
modify,
distribute,
make
or sell
designs or
hardware based on that design

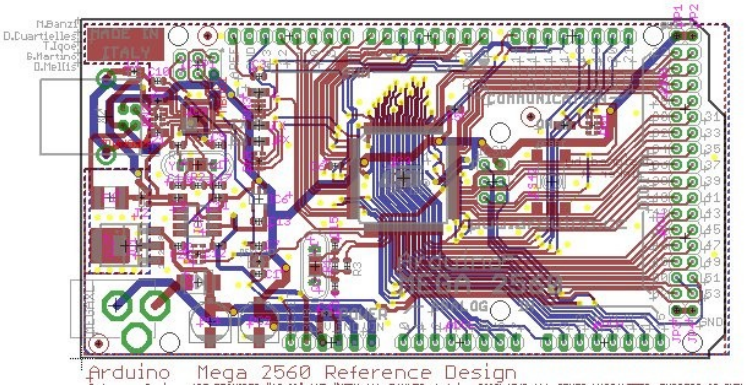
Open Source Hardware

Documentation required for electronics:

☑ Schematics



☑ Board Layout



Editable source files for CAD software *(KiCad, EAGLE, Altium, etc)*

☑ Bill of Materials *(BOM)*

Best practice: all components available in **low quantity distribution**

Open Source Hardware

Publish documentation with an

Open Source license:

- Creative Commons Share-Alike: **CC-BY-SA**
  - *Non-Commercial (**NC**) clause is **NOT** acceptable*
    http://www.oshwa.org/2014/05/21/cc-oshw/
- Copyleft: **GPLv2**, **GPLv3**
- Permissive: **Apache, BSD, MIT**
- OSHW inspired: **CERN OHL, TAPR, SolderPad**

CERN Open Hardware Licence

http://www.ohwr.org/projects/cernohl/wiki

- Originally written for **CERN** designs hosted in the **Open Hardware Repository**

- Can used by **any designer** wishing to **share design** information using a **license compliant** with the **OSHW definition criteria**.

- **CERN OHL version 1.2:**
  http://www.ohwr.org/documents/294
  Contains the license itself and a guide to its usage

CERN Open Hardware Licence

http://www.ohwr.org/projects/cernohl/wiki

***Myriam Ayass**, legal adviser at CERN and author of the CERN OHL:*

- OHL is to hardware what GPL is to software
- Same principles as Free or Open Source software
- **Anyone should be able to see the source *(the design documentation in case of hardware)*, study it, modify it and share it.**

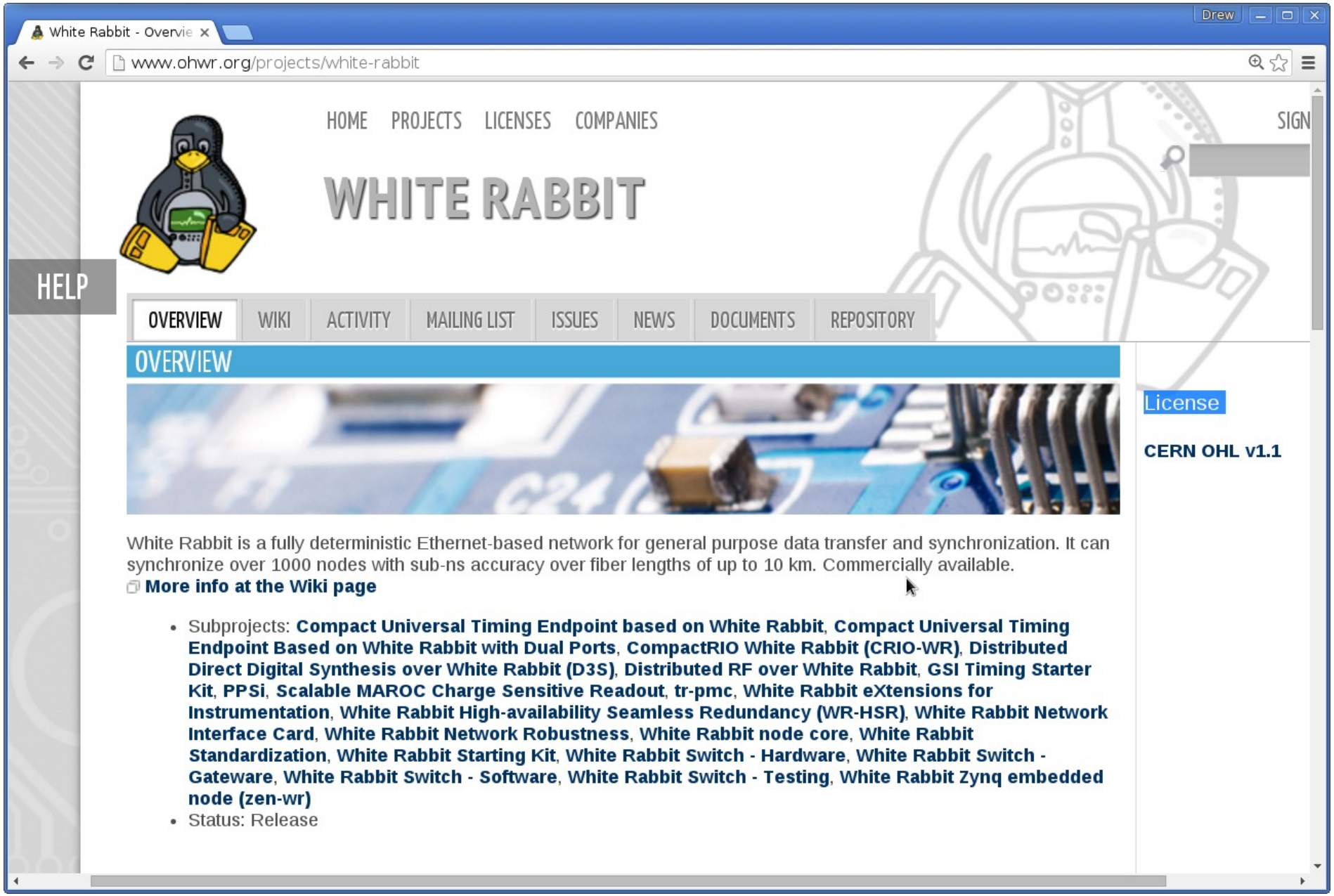
Open Hardware Repository

http://www.ohwr.org/

- **Collaborate** on Open Hardware designs
- **Peer review** for small teams or solo designers
- Origins in **experimental physics laboratories**
- Enable teams to **work together** to solve problems
- **More fun** than isolation & results in **better hardware**

Example: White Rabbit

http://www.ohwr.org/projects/white-rabbit



Javier Serrano, Open Hardware at CERN

https://vimeo.com/127579456

- Physicist and Electronics Engineer at CERN
- co-author of the **CERN Open Hardware License**
- creator of the **Open Hardware Repository**

Licenses, Copyright and Patents can get confusing!

Review of Popular OSHW Licenses

https://vimeo.com/110682815

Talk by Ari Douglas at OHS 2014

Open Source Hardware

What is the spirit of Open Source?

- Publish everything that will:

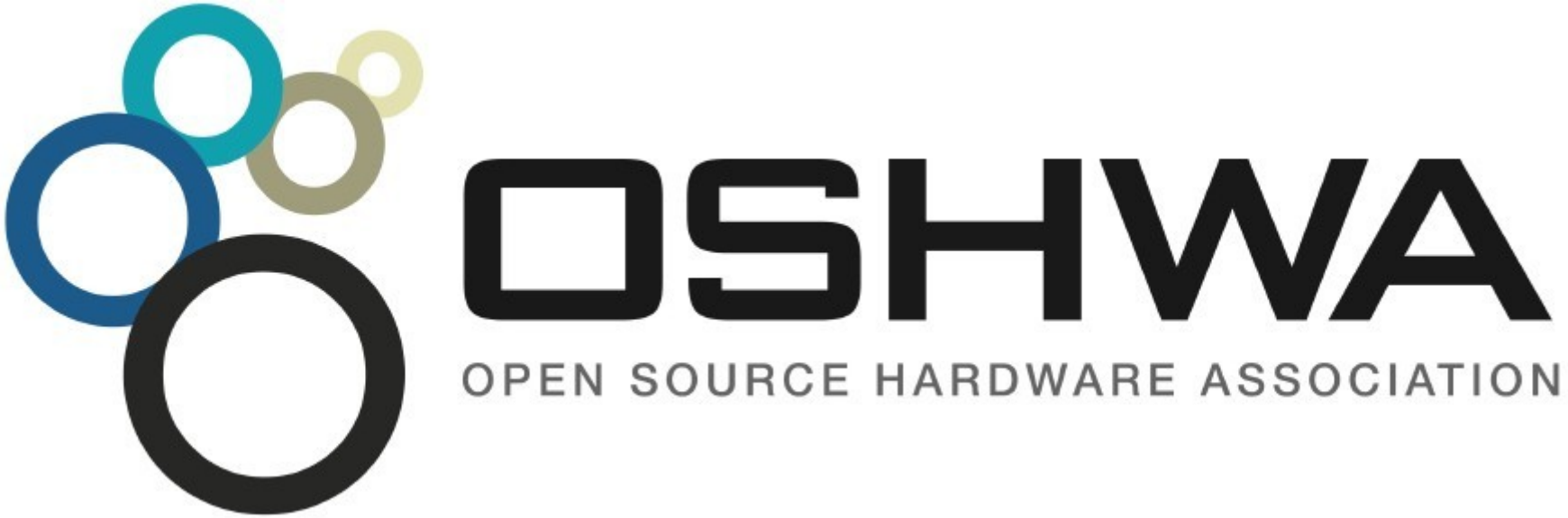
  enable collaborative development

- The goal is NOT to just check a box on a marketing flyer or add keywords to a Kickstarter campaign

Open Source Hardware Association

http://www.oshwa.org

- US Federal 501(c) non-profit
- Hosts the OSHW definition: http://www.oshwa.org/definition/
- *“aims to be the voice of the open hardware community, ensuring that technological knowledge is accessible to everyone, and encouraging the collaborative development of technology”*



Open Source Hardware

- **May and Must** attributes
  - PDF poster: http://www.oshwa.org/wp-content/uploads/2014/08/OSHW-May-and-Must.pdf
- **Quick Reference Guide:**
  - http://www.oshwa.org/open-source-quick-reference-guide/
- **Best Practices:**

  http://www.oshwa.org/sharing-best-practices/

Open Hardware Summit *(OHS)*

- **OHS 2016:** http://2016.oshwa.org/

  October 7th in **Portland**, Oregon

- ***6*** *prior summits:*
  - **2010, 2011:** New York Hall of Science
  - **2012:** Eyebeam *(NYC)*
  - **2013:** MIT *(~Boston)*
  - **2014:** Roma, Italia!
  - **2015:** Philadelphia

Open Hardware Summit *(OHS)*

- **2015 videos:** http://2015.oshwa.org/

2015 Summit Late Afternoon Sessions

4 months ago

2015 Summit Early Afternoon Sessions

4 months ago

OHS 2015

The Best Open Hardware Summit Ever.

2015 Summit Late Morning Sessions

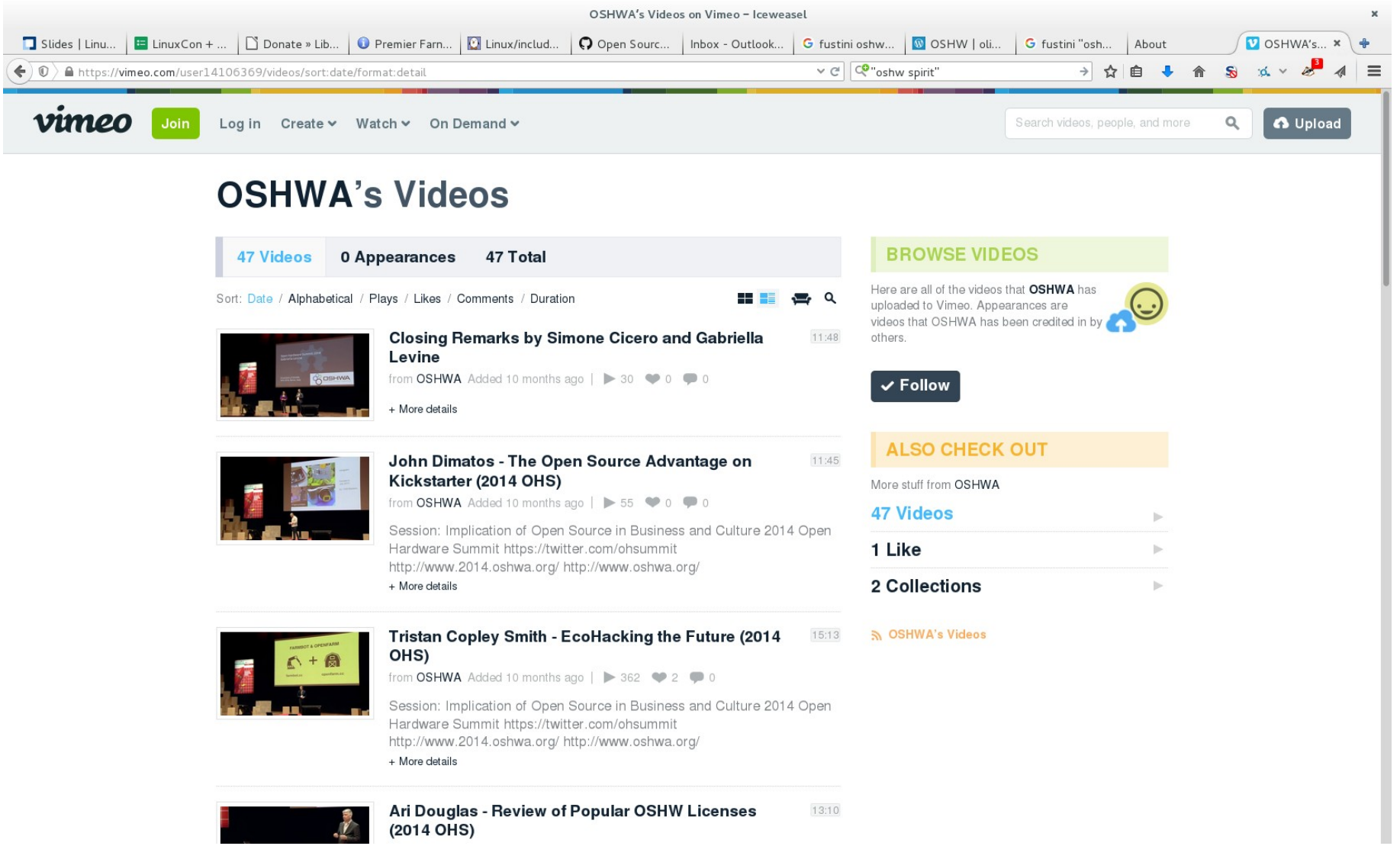
4 months ago

2015 Summit Early Morning Sessions

4 months ago

Open Hardware Summit *(OHS)*

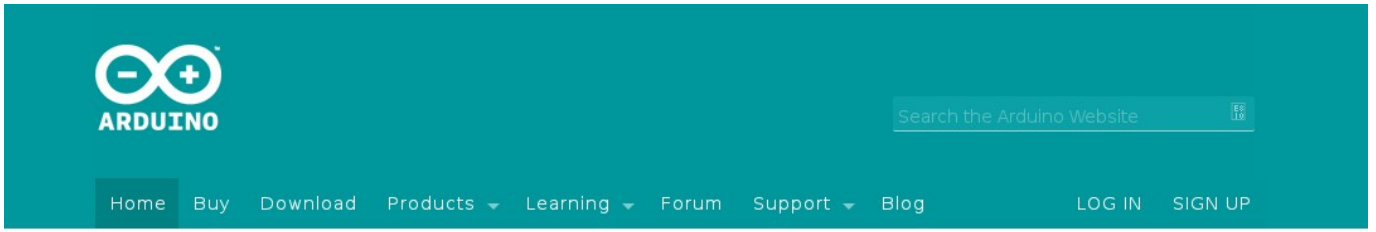
- **2014 videos:** https://vimeo.com/user14106369/videos



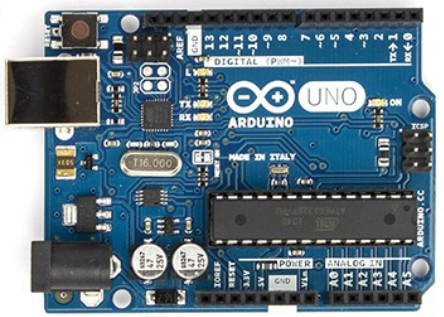
Achieved Critical Mass by Sharing:

Arduino

http://arduino.cc/



Arduino Uno



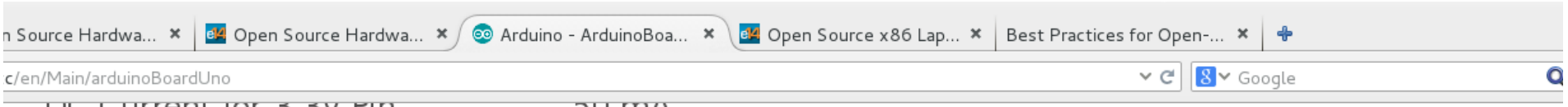
How did it come to be?

Arduino: The Documentary

https://vimeo.com/18539129

Example: Arduino UNO Design Files

https://www.arduino.cc/en/Main/ArduinoBoardUno



DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

Schematic & Reference Design

EAGLE files: arduino-uno-Rev3-reference-design.zip (NOTE: works with Eagle 6.0 and ne

Schematic: arduino-uno-Rev3-schematic.pdf

Note: The Arduino reference design can use an Atmega8, 168, or 328, Current models u

ATmega328, but an Atmega8 is shown in the schematic for reference. The pin configura

beagleboard.org

- Open Source Hardware ARM Linux boards
- Developed by BeagleBoard.org Foundation and BeagleBoard.org Community
- Founded by Texas Instruments engineers Jason Kridner and Gerald Coley
- Mascot is Boris the Beagle!
- Manufacturers: CircuitCo, element14 & Seeed



Previous Beagles

- BeagleBoard:
  - 2008
  - first affordable ($150) ARM single board computer (SBC)
  - Open Source Hardware!

- BeagleBone:
  - 2011
  - $89
  - 256MB RAM
  - 720MHz, ARM Cortex A8
  - ***fits in an Altoids-tin!***

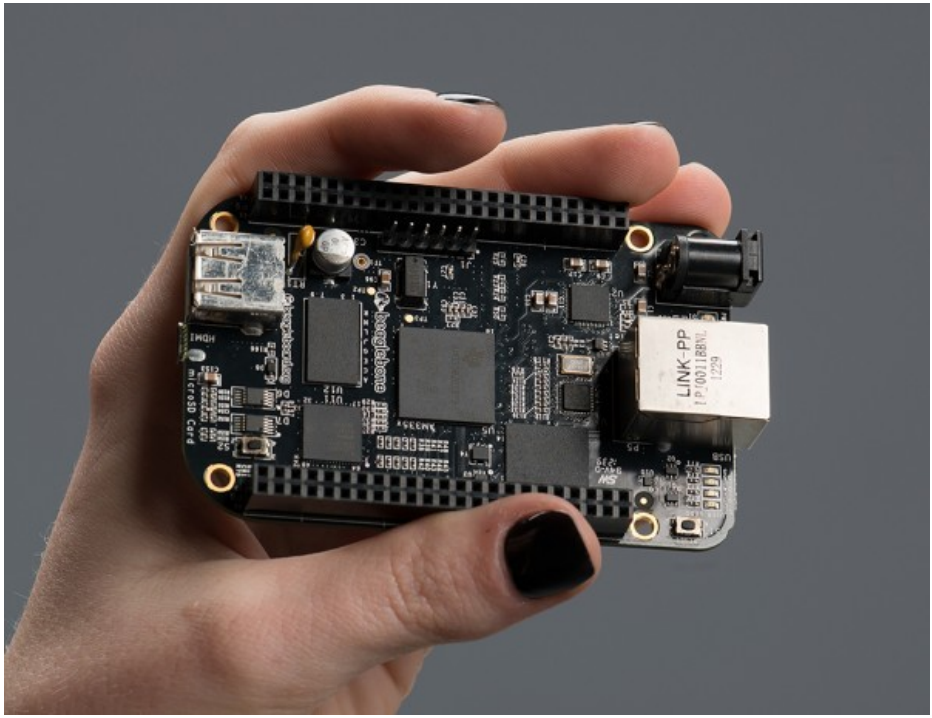
BeagleBone Black *(~$50)*

http://beagleboard.org/black

- Flexible open hardware and software development platform

  http://elinux.org/Beagleboard:BeagleBoneBlack#Hardware_Files

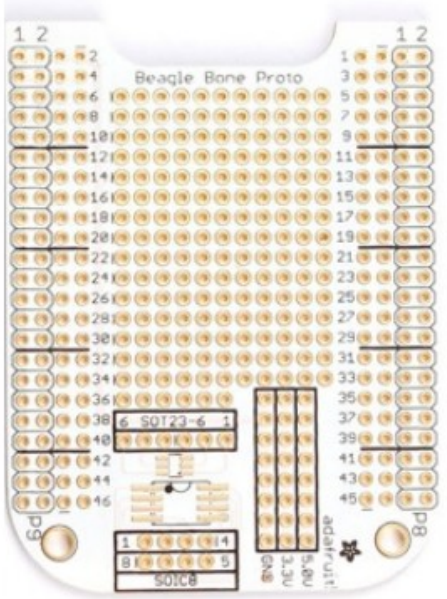
- Fast and flexible
  - 1-GHz Sitara ARM
  - 2x 200-MHz PRUs
  - 512 MB DDR3
  - On-board HDMI & Ethernet
  - USB 2.0 Host
  - GPIO: 65 digital I/O, 7 analog inputs, UART, I2C, SPI



BeagleBone Black

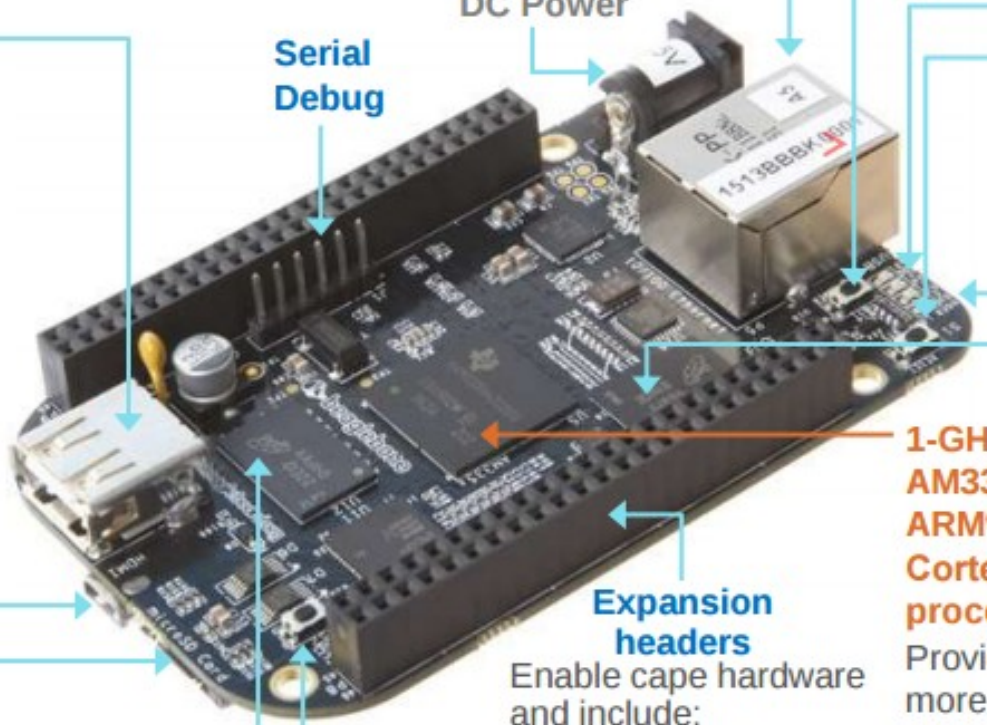
http://beagleboard.org/black

- Ready to use out of the box:
  - USB provides power and client network
  - Built-in “bone101” tutorials in Bonescript
  - Browser-based IDE *(Cloud9)*
  - 4GB eMMC flashed with Debian



- BeagleBone Capes:
  - http://elinux.org/Beagleboard:BeagleBone_Capes
  - Just another word for daughter board
  - up to 4 stacked depending on resources used

BeagleBone Black board features



10/100 Ethernet

USB Host
Easily connects to almost any everyday device such as mouse or keyboard

microHDMI
Connect directly to monitors and TVs

microSD
Expansion slot for additional storage

512MB DDR3
Faster, lower power RAM for enhanced user-friendly experience

Serial Debug

DC Power

Boot Button

Power Button

LEDS

Reset Button

USB Client
Development interface and directly powers board from PC

4-GB on-board storage using eMMC
- Pre-loaded with Debian Linux Distribution
- 8-bit bus accelerates performance
- Frees the microSD slot to be used for additional storage for a less expensive solution than SD cards

1-GHz Sitara AM335x ARM® Cortex™-A8 processor
Provides a more advanced user interface and up to 150% better performance than ARM11

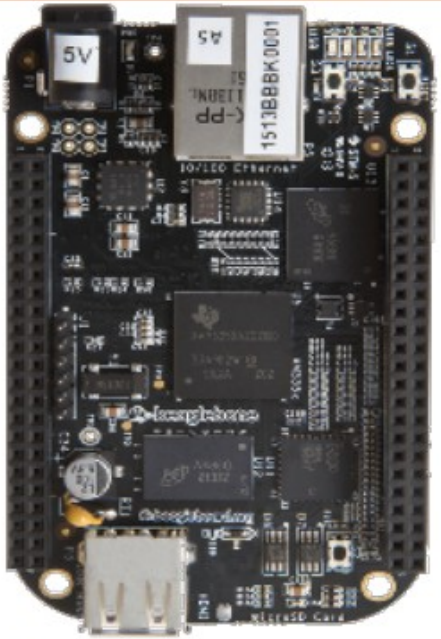
Expansion headers
Enable cape hardware and include:
- 65 digital I/O
- 7 analog
- 4 serial
- 2 SPI
- 2 I2C
- 8 PWMs
- 4 timers
- And much much more!

Money saving extras:
- Power over USB
- Included USB cable
- 4-GB on-board storage
- Built-in PRU microcontrollers

Cape Expansion Headers

DGND	1	2	DGND
VDD_3V3	3	4	VDD_3V3
VDD_5V	5	6	VDD_5V
SYS_5V	7	8	SYS_5V
PWR_BUT	9	10	SYS_RESETn
UART4_RXD	11	12	GPIO_60
UART4_TXD	13	14	EHRPWM1A
GPIO_48	15	16	EHRPWM1B
SPI0_CS0	17	18	SPI0_D1
I2C2_SCL	19	20	I2C2_SDA
SPI0_D0	21	22	SPI0_SCLK
GPIO_49	23	24	UART1_TXD
GPIO_117	25	26	UART1_RXD
GPIO_115	27	28	SPI1_CS0
SPI1_D0	29	30	GPIO_122
SPI1_SCLK	31	32	VDD_ADC
AIN4	33	34	GNDA_ADC
AIN6	35	36	AIN5
AIN2	37	38	AIN3
AIN0	39	40	AIN1
GPIO_20	41	42	ECAPPWM0
DGND	43	44	DGND
DGND	45	46	DGND

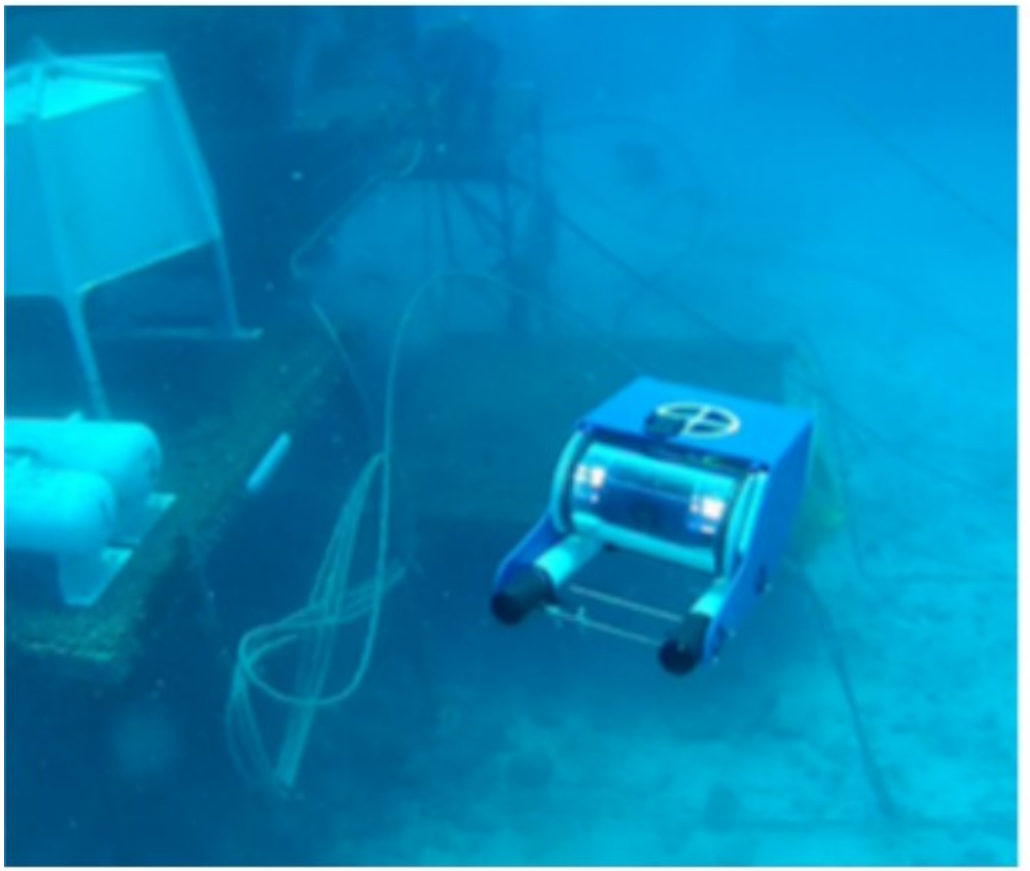
beagleboard.org



LEGEND
Power/Ground/Reset
Available Digital
Available PWM
Shared I2C Bus
Reconfigurable Digital
Analog Inputs (1.8V)

DGND	1	2	DGND
MMC1_DAT6	3	4	MMC1_DAT7
MMC1_DAT2	5	6	MMC1_DAT3
GPIO_66	7	8	GPIO_67
GPIO_69	9	10	GPIO_68
GPIO_45	11	12	GPIO_44
EHRPWM2B	13	14	GPIO_26
GPIO_47	15	16	GPIO_46
GPIO_27	17	18	GPIO_65
EHRPWM2A	19	20	MMC1_CMD
MMC1_CLK	21	22	MMC1_DAT5
MMC1_DAT4	23	24	MMC1_DAT1
MMC1_DAT0	25	26	GPIO_61
LCD_VSYNC	27	28	LCD_PCLK
LCD_HSYNC	29	30	LCD_AC_BIAS
LCD_DATA14	31	32	LCD_DATA15
LCD_DATA13	33	34	LCD_DATA11
LCD_DATA12	35	36	LCD_DATA10
LCD_DATA8	37	38	LCD_DATA9
LCD_DATA6	39	40	LCD_DATA7
LCD_DATA4	41	42	LCD_DATA5
LCD_DATA2	43	44	LCD_DATA3
LCD_DATA0	45	46	LCD_DATA1

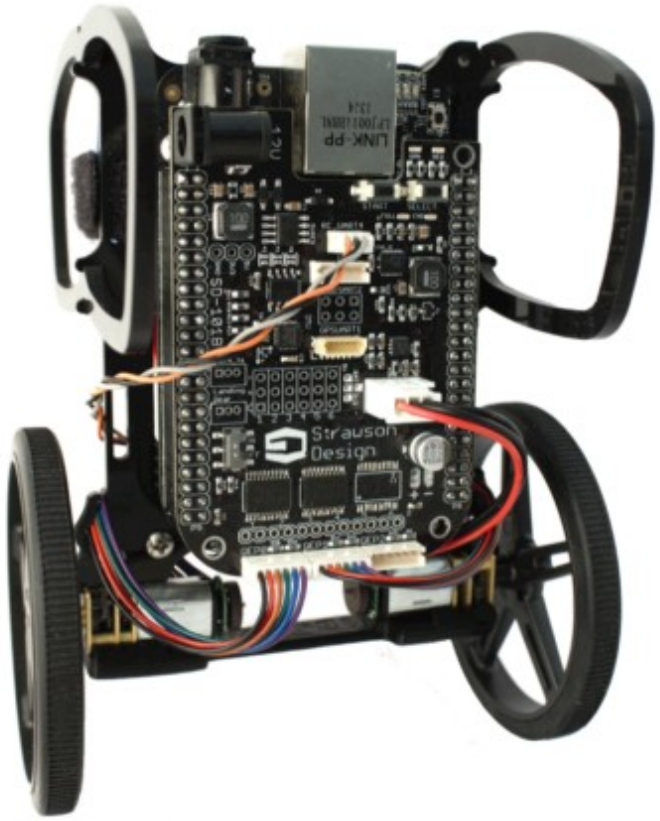
OpenROV http://www.openrov.com/



- Open-source underwater robot
- Community creating more accessible, affordable and awesome tools for underwater exploration
- Started by people wanting to explore an underwater cave
- Successfully Kickstarter'd

BeagleMIP

UCSD



- Self-Balancing robot powered by the BeagleBone Black and the Novus Robotics Cape
- Hackable Open Source Robotics Platform for Fun and Education
- Developed at the University of California, San Diego to Teach Advanced Digital Control Systems

BeagleBone Black

http://beagleboard.org/black

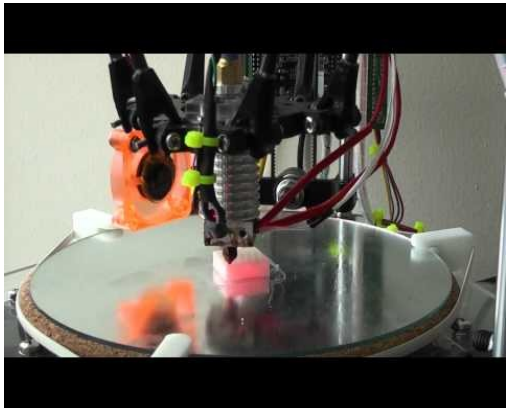
- **What are PRUs?**
  - "**P**rogrammable **R**eal-**T**ime **U**nits"
  - 32-bit RISC processors at 200MHz with single-cycle pin access for hard real-time
  - Optimized for packet processing/switching and software implementation of peripherals
- **Why use PRUs?**
  - Dedicated function, free from the running OS
  - Real-time because it can't be interrupted
  - Low latency from input to output
  - You can't interface external MCU to DDR memory!

BeagleBone Black

http://beagleboard.org/black

- **Example PRU usage:**
  - **Tight control loops** driving mobile robot, CNC machine or 3D printer
  - **Custom Protocols:** WS28x LED strips, DMX512, EtherCAT, ProfiBUS, ProfiNET

- **Popular projects:**
  - LEDscape: https://trmm.net/Category:LEDscape
  - MachineKit *(fork of LinuxCNC)*: http://www.machinekit.io/



BeagleBoard.org Logo program

http://beagleboard.org/logo

- Third party product that licenses use of logo
- Verified to run BeagleBoard.org software image
- Open hardware design materials
- Targeting new applications

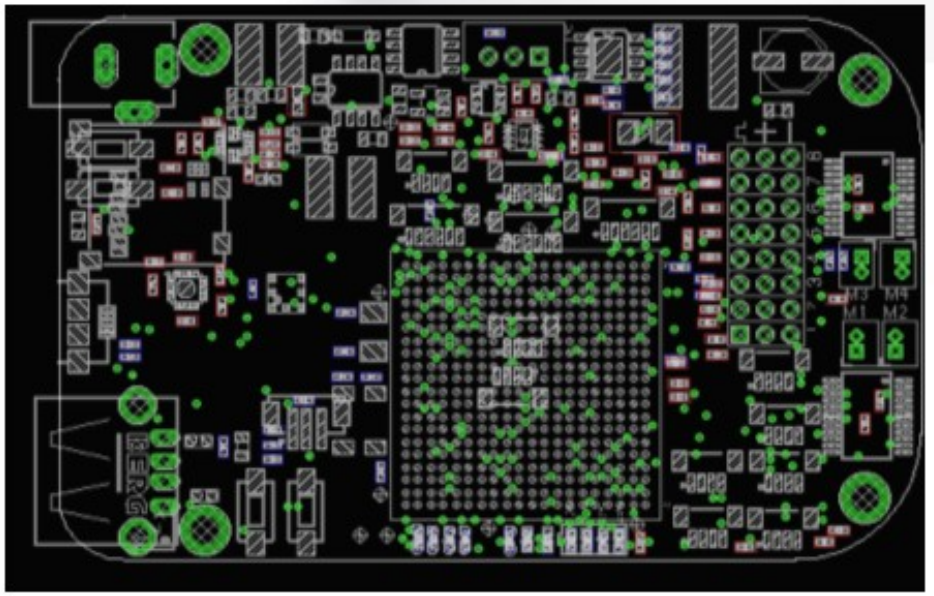
SeeedStudio BeagleBone Green

http://beagleboard.org/green

- Available now **$40**
- Compared to Black
  - Removes HDMI
  - Adds Grove connectors
- Affordable and great for quick-connect to I2C and UART sensors
- SCL = P9_19
  SDA = P9_20
- TXD = P9_21
  RXD = P9_22

BeagleBone Blue and UCSD EduLine

Robotics for all!!

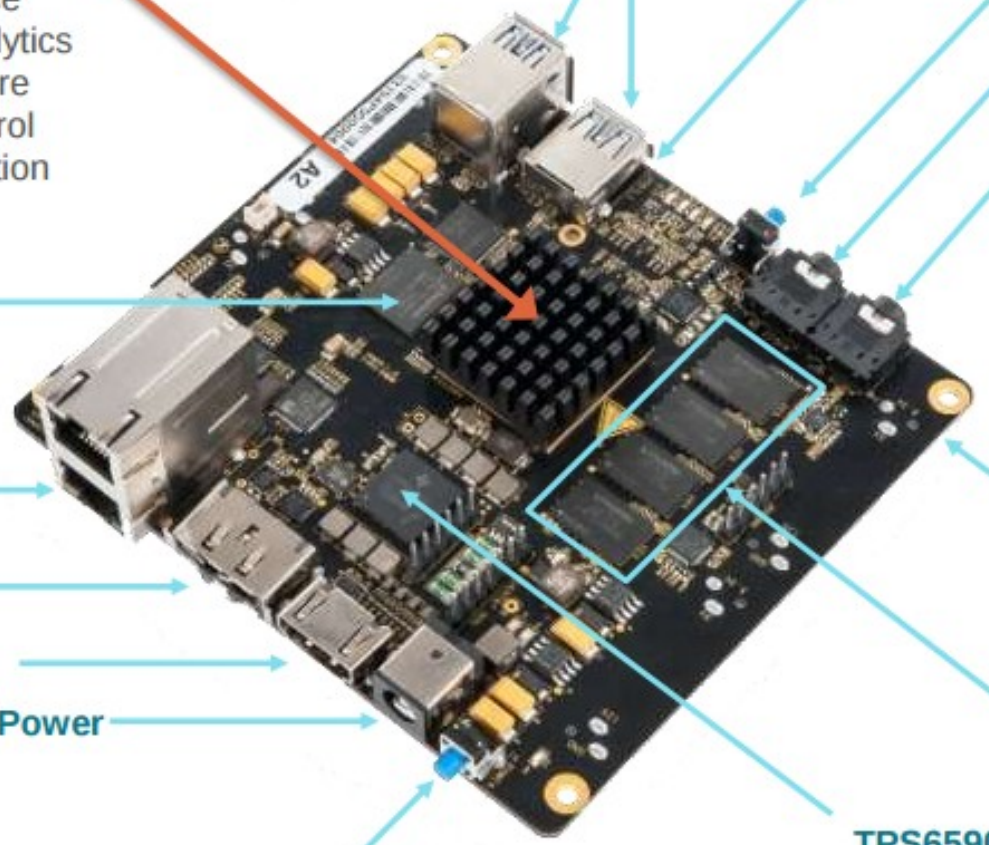


- Open robotics education solution
  - Based on open BeagleBone Black
  - Catalog components & low-complexity
  - Full-featured 1GHz Debian Linux
  - Mechanical, electrical and S/W source
- Affordable single board controller
  - Battery: 2-cell LiPo support with balancing, 6-16V charger input
  - Wireless: 802.11agn, Bluetooth 4.0 and BLE
  - Motor control: 8 6V servo out, 4 DC motor out, 4 quad enc in
  - Sensors: 9 axis IMU, barometer
  - Easy connect interfaces: GPS, DSM2 radio, UARTs, SPI, I2C, analog, USB, uSD, buttons, LEDs
- Outstanding support ecosystem
  - Complete mechanics and software for EduMIP, EduRover and EduMAV
  - Full curriculum available via MOOC
  - Graphical programming option

BeagleBoard-X15

High performance Sitara™ AM5728 processor

- 1.5GHz ARM® Cortex®-A15 for processing and user interface
- 750-MHz C66x DSP for analytics
- Quad core PRU and dual core Cortex-M4 for real time control
- Video and Graphic acceleration



USB3.0 Host
3x HUB

Bottom side
µSD card slot
Micro USB 2.0 slave

Reset button

Audio in

Audio out

eMMC
4GB

2x Ethernet Ports
Gigabit

eSATA

HDMI

12V DC Power

Power button

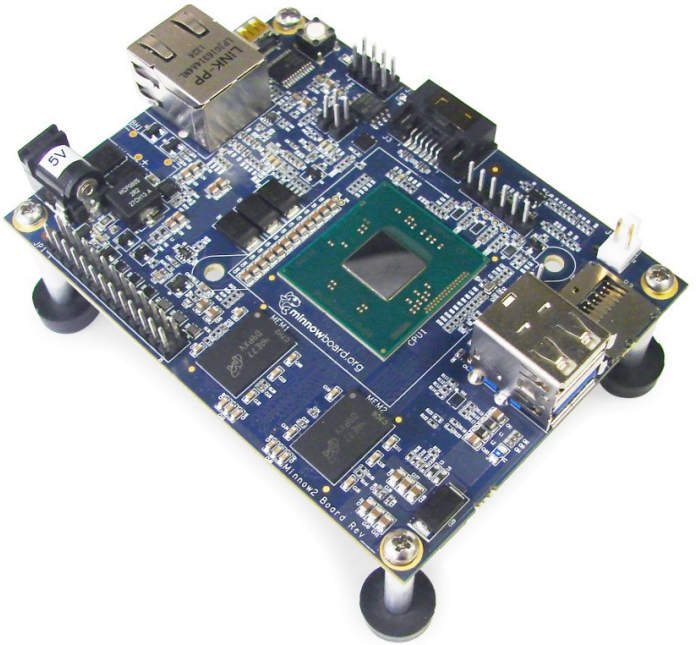
TPS659037
Power
Management IC

DDR3L
2GB

Bottom side
Expansion connectors
20-pin ARM JTAG

MinnowBard

http://www.minnowboard.org/



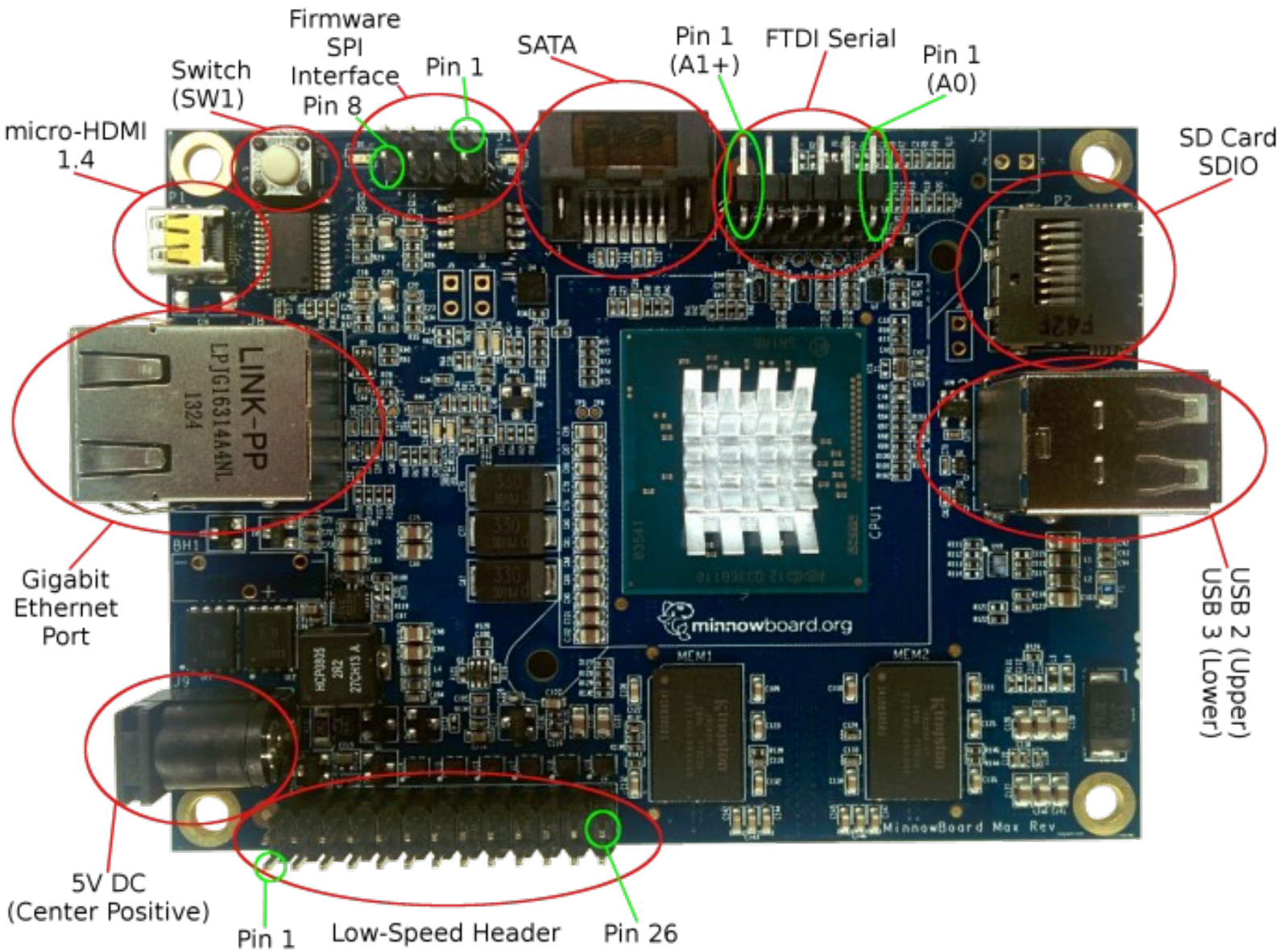
- 64-bit Intel Atom *“Bay Trail”*
- MinnowBoard MAX:
  - $139 MSRP: E3825 (dual-core, 1.33 GHz)
- MinnowBoard Turbot
  - $139 MSRP: E3826 (dual-core, 1.46 GHz)
- USB 3.0, SATA, PCIe, Gigabit Ethernet, HDMI
- Integrated Intel HD Graphics
  - Open Source Mainline Linux drivers!

minnowboard.org

OSHW Design Files

- Manufactured by CircuitCo *(MAX)* & ADI *(Turbot)*
- Released under Creative Commons **CC-BY-SA**
- Download:
  http://www.elinux.org/Minnowboard:MinnowMax#Design_Files
  - ***[x]*** **Schematic** (Orcad DSN & PDF)
  - ***[x]*** **Board Layout** (Allegro BRD & Gerbers)
  - ***[x]*** **Bill of Materials**

MinnowBoard I/O *(MAX & Turbot)*

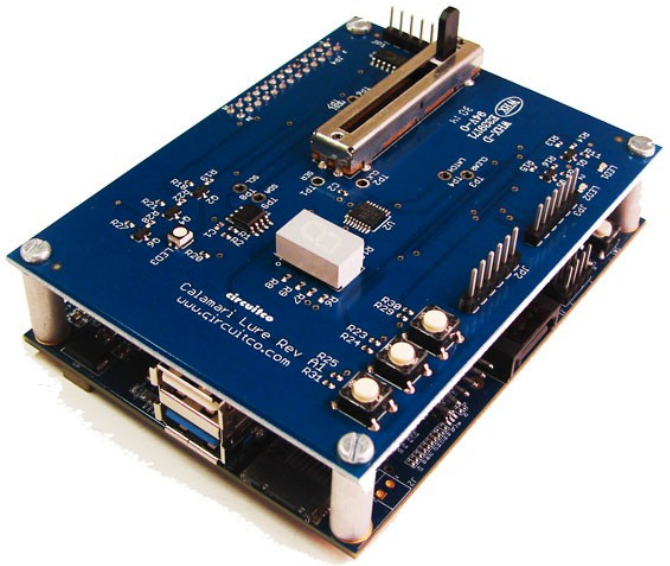


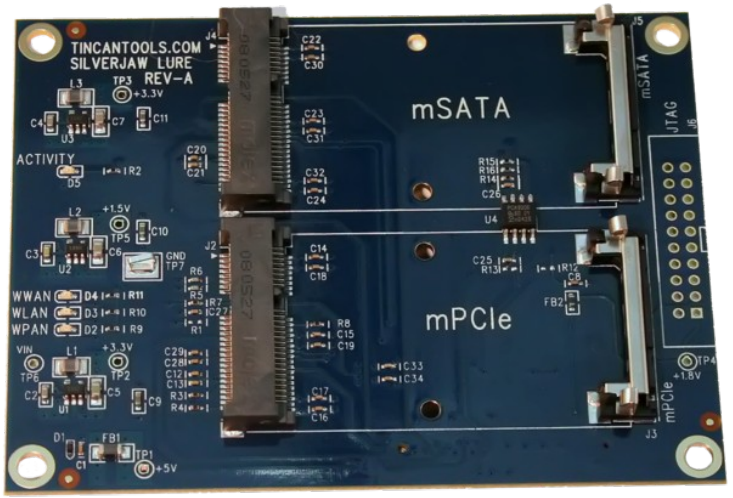
minnowboard.org

Expansion Port Details

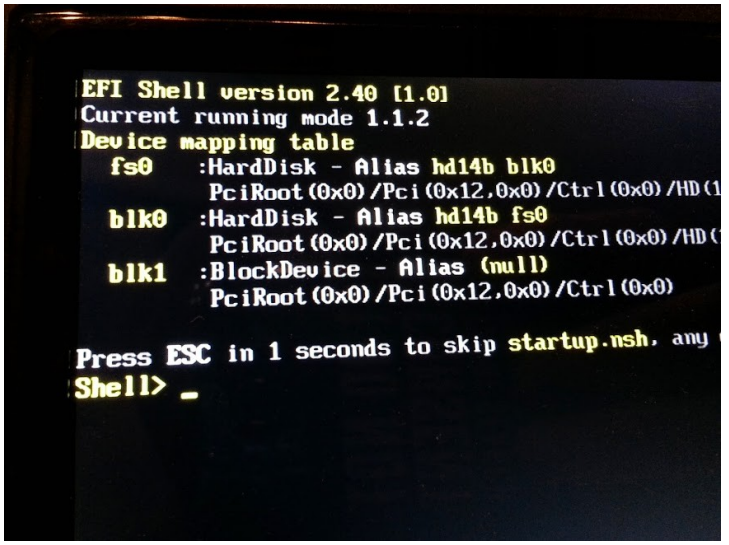
- **Low-Speed Expansion port:**
  - 2×13 (26-pin) male 0.1″ pin header.
  - SPI, I2C, I2S Audio, 2x UARTs, 8x GPIO, 2x PWM
- **High-Speed Expansion port:**
  - 60-pin, high-density connector.
  - 1x PCIe Gen 2.0 Lane, 1x SATA2 3Gb/sec, USB 2.0 host, I2C, GPIO, JTAG

Lures: expansion boards





- **Calamari Lure:** $30
  - http://elinux.org/Calamari_Lure
  - SPI Based ADC, 10K Slider POT, RGB LED, 2 PWM LEDS, 2 TTL UART Headers, 7-Segment Display with 595 shift register, I2C, EEPROM, 3 Buttons
- **Silverjaw Lure:** $50
  - http://wiki.minnowboard.org/Silverjaw_Lure
  - dual break-out board providing both an mPCIe and mSATA slot



EFI (Firmware)

- MinnowBoard uses a **UEFI** system level firmware, and provides both the **UEFI** shell, and a typical BIOS style menu interface.

- Intel EFI Firmware update for MAX: https://uefidk.com/content/minnowboard-max

- eLinux Wiki page on BIOS: http://www.elinux.org/Minnowboard:MaxBios

OlinuXino

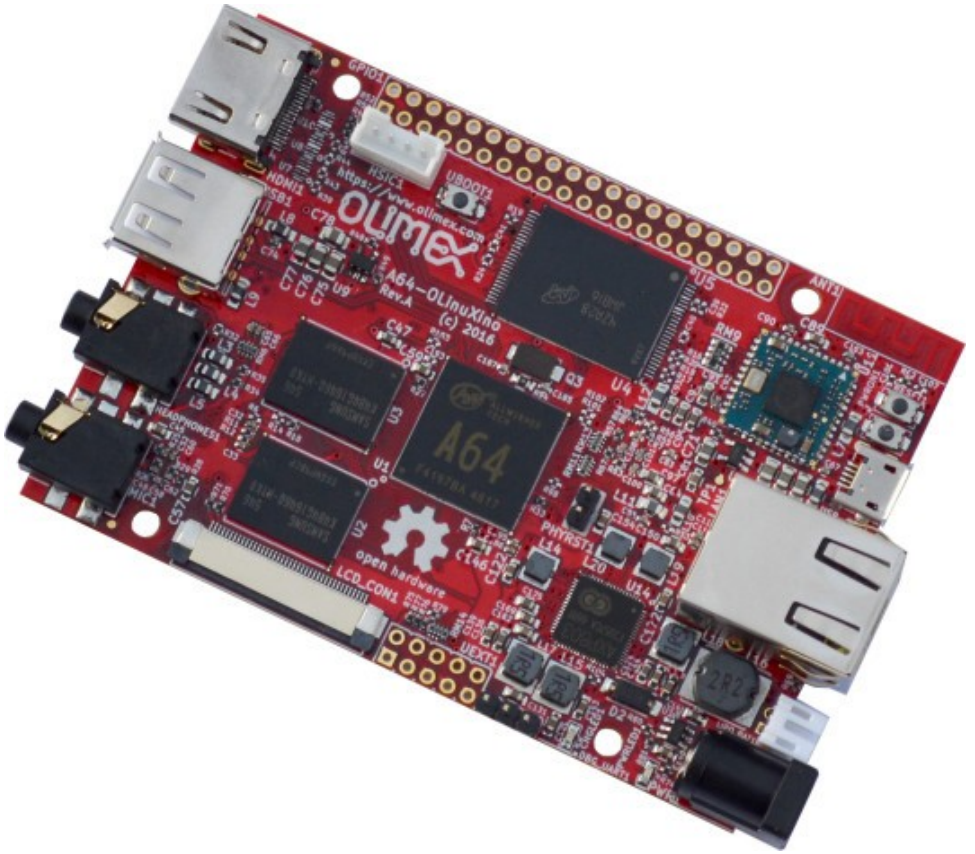
https://www.olimex.com/Products/OLinuXino/open-source-hardware

- Open Source Hardware low cost Linux computers
- Designed & manufactured by **Olimex** in **Bulgaria**
- Originally **Freescale** i.MX233
- Newer models have **Allwinner**: A10, A13, A20, H3
- Agreement with Allwinner for longevity support and sell individual chips to customers
- *“Open Source Hardware (OSHW), why it matters and what is pseudo OSHW”*

https://olimex.wordpress.com/2016/01/13/open-source-hardware-oshw-why-it-matters-and-what-is-pseudo-oshw/

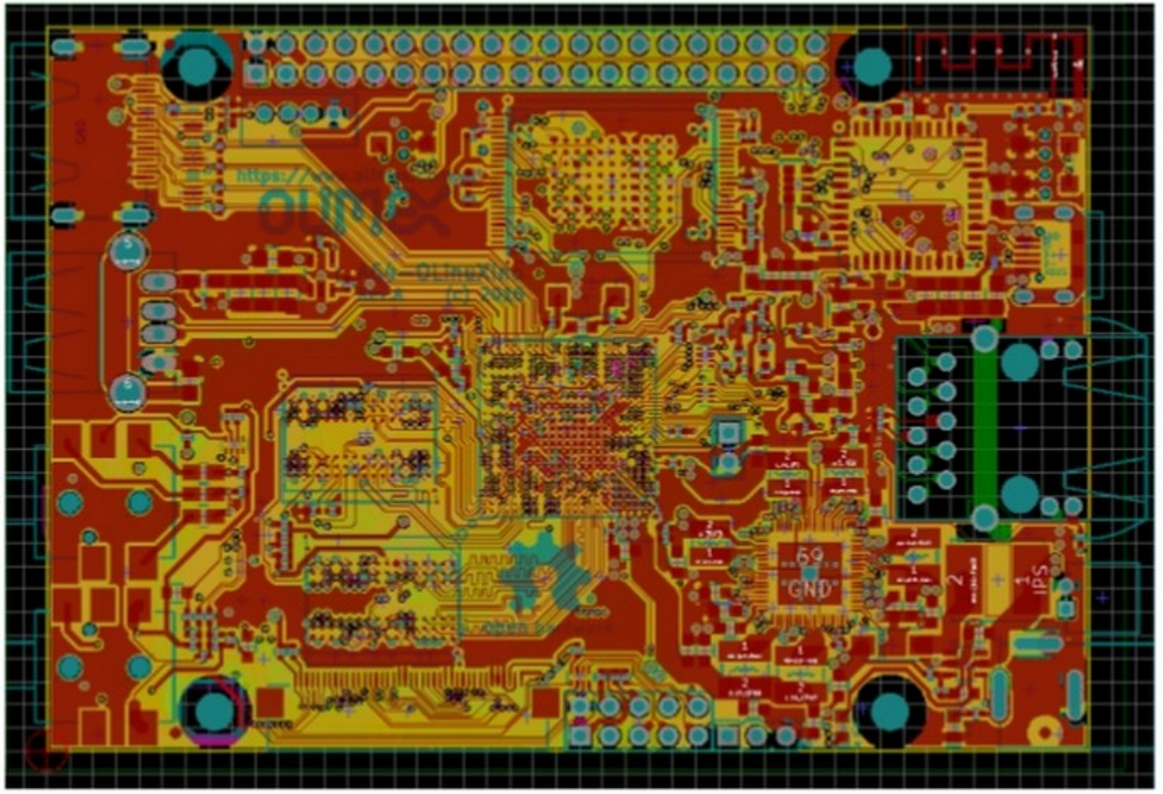
A64-OlinuXino:

- https://olimex.wordpress.com/tag/a64/
- Allwinner A64: Quad Core 64-bit ARM Cortex-A53
- Designed completely with KiCAD
- 1GB RAM (2GB is possible), 4GB fast SLC eMMC Flash, WiFi+BLE4.0 module



Using FOSS tools for OSHW project

Designing with KiCAD of 64-bit ARM board

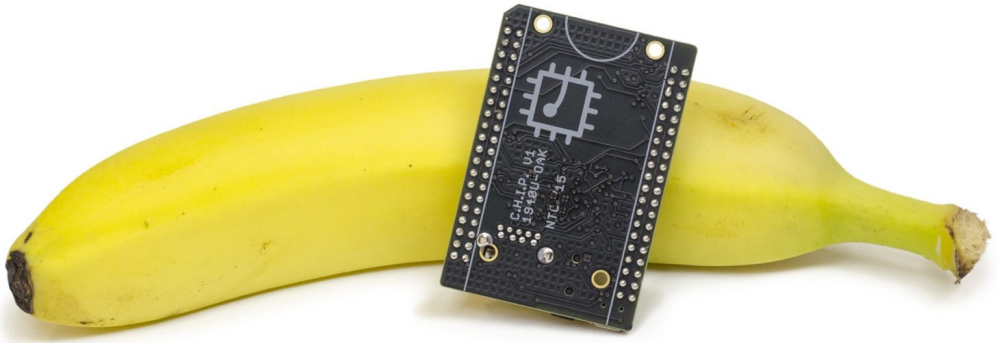


Tsvetan Usunov, OLIMEX Ltd

FOSDEM 2016

http://www.slideshare.net/olimexbulgaria/designing-with-kicad-of-64bit-arm-board

CHIP

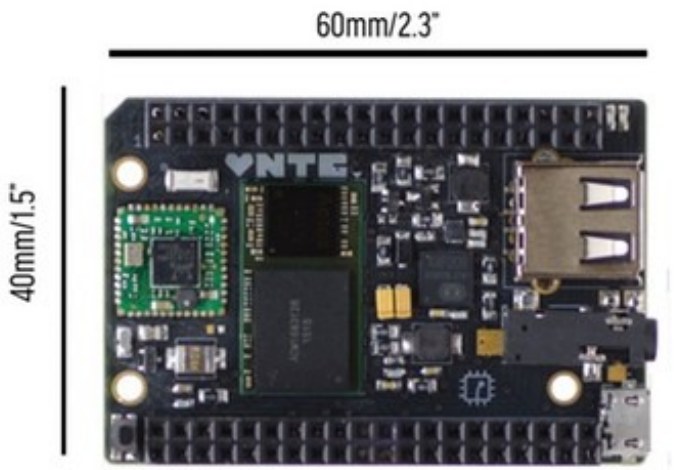


The World's First $9 Computer

- http://getchip.com/
- **Next Thing Co. in Oakland**
- **Kickstarter in 2015:**
  - **39,560 backers**
  - **$2,071,927 pledged**

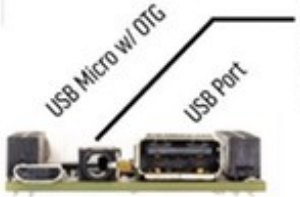
1GHz + 512MB + 4GB

processor ram storage



R8

1GHZ Allwinner A13 Compatible SoC
Mali400 GPU w/ OpenGLES 2.0 & OpenVG 1.1
512MB DDR3 Ram
4GB NAND Flash Storage



Composite Video
HDMI & VGA Out via adapter
Headphone Audio Out
Mic In

open source hardware

C.H.I.P. is built with Making in Mind

Realtek 2-in-1 Bluetooth 4.0 + WIFI B/G/N
I2C + SPI + UART + 8 x GPIO
Camera Sensor Support (MIPI-CSI)
Native LCD Support 4.3-8"
Battery Power & Charging

Fast Boot Debian Based Linux OS
Over The Air Updates
OpenGLES 2.0
OpenVG 1.1

WIFI & Bluetooth

802.11B/G/N 4.0

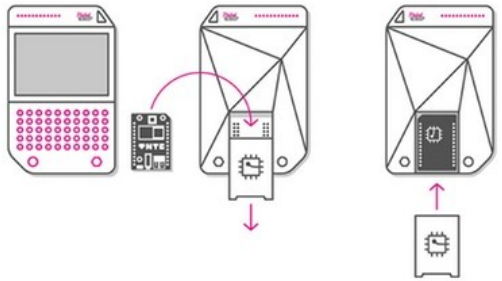
Battery Power & Charging Built In!

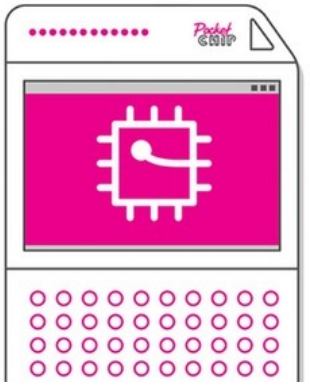
Run CHIP for Hours with a Single Cell Lipo.

PocketC.H.I.P. makes C.H.I.P. portable!

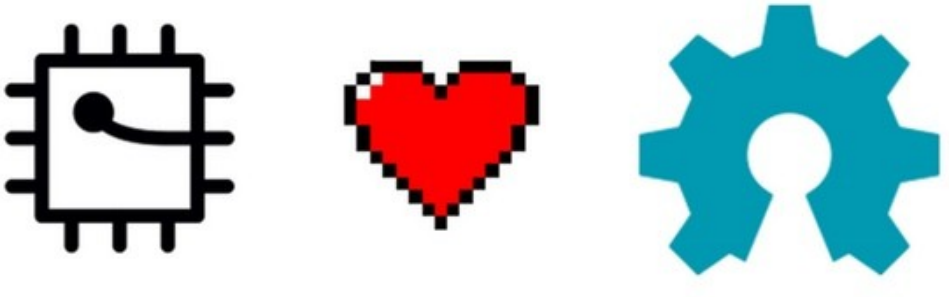
https://www.kickstarter.com/projects/1598272670/chip-the-worlds-first-9-computer/posts/1245278

- 3,000 mAH battery (5 hours)
- 4.3" 470px x 272px screen w/ resistive touch
- Full Super-Clicky QWERTY keyboard
- Rugged Injection Molded Shell
- Fully open source
-
-





CHIP Hardware repo



- https://github.com/NextThingCo/CHIP-Hardware
- **Schematics**
- **PCB Layout**
- **Bill of Materials *(BOM)***
- **Datasheets for BOM:**

  https://github.com/NextThingCo/CHIP-Hardware/tree/master/CHIPv0_21-BOM-Datasheets

Mainline C.H.I.P. Kernel Changes

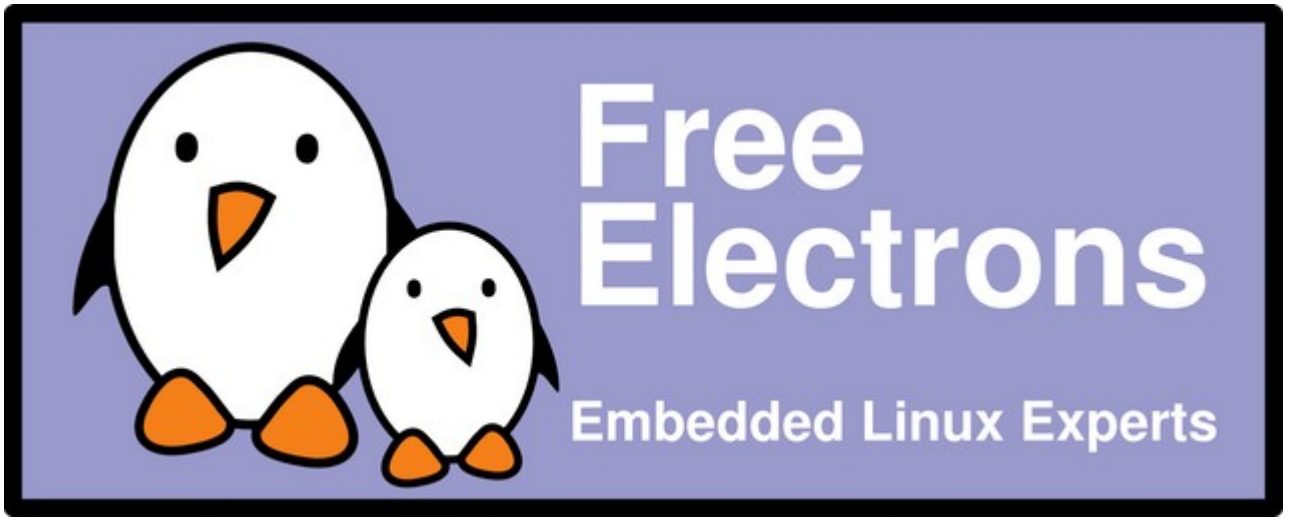
- **Kickstarter post: *"All about Open Source"***

  https://www.kickstarter.com/projects/1598272670/chip-the-worlds-first-9-computer/posts/1247188

- Run **official & current** version of **Linux kernel**

- Merge changes into **Linus Torvald's tree** in a process called **"Mainlining"**

- **Linux-Sun-Xi** community has already made great progress on for **Allwinner SoCs: https://linux-sunxi.org**

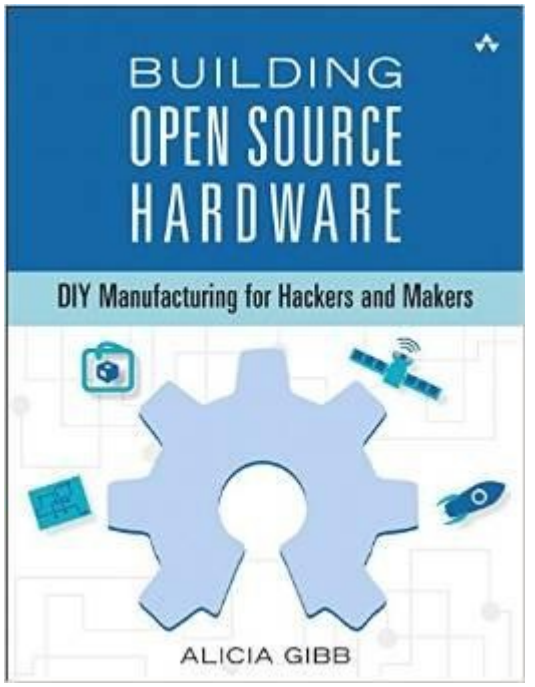


- Contracted by Next Thing Co to **support the CHIP in mainline Linux kernel:**
  - ***"Free Electrons working on the $9 C.H.I.P. computer"***

    http://free-electrons.com/blog/free-electrons-chip-nextthing/
- **Free Electrons** has been supporting **Allwinner** processors in the **mainline Linux kernel** for several years
- Free Electrons engineer **Maxime Ripard** is the **maintainer** of the **Allwinner SoC support**

Resources

- Join OSHWA!
  - http://www.oshwa.org/membership/
- Subscribe to the mailing list:
  - http://lists.oshwa.org/listinfo/discuss
- Follow on Twitter:
  - @OHSummit
  - @oshwassociation
- Building Open Source Hardware
  - http://www.amazon.com/Building-Open-Source-Hardware-Manufacturing/dp/0321906047/



BONUS SLIDES

What about silicon?

- **LowRISC!**
  - http://www.lowrisc.org/
  - “lowRISC is producing fully open hardware systems. From the processor core to the development board, our goal is to create a completely open computing eco-system”

Novena laptop

https://www.crowdsupply.com/sutajio-kosagi/novena

- Created by **Bunnie & xobs**!
  - Chumby! Hacking the X-Box! Amazing reverse engineers:
    - *The Exploration and Exploitation of an SD Memory Card*

      https://www.youtube.com/watch?v=CPEzLNh5YIo
- **100%** Open Source Hardware laptop
- **Quad-core** 1.2GHz Freescale **ARM** CPU
- **FPGA!** 4GB RAM, WiFi, **2x** Ethernet, SSD

Lulzbot 3-D Printers

https://www.lulzbot.com

100% Open Source

Hardware & Software

- FSF Respects Your Freedom certified

  https://www.fsf.org/resources/hw/endorsement/respects-your-freedom

Respects Your Freedom

- Hardware product certification by the Free Software Foundation (FSF)

- Certified products: “**respect your freedom and your privacy, and will ensure that you have control over your device.**”

- Hardware design can be proprietary, but all software & firmware must be Free/Libre

Respects Your Freedom

- **Libreboot X200 laptop**
  - http://minifree.org/product/libreboot-x200/
  - reconditioned ThinkPad X200
  - libreboot firmware (free BIOS/UEFI replacement)
  - Trisquel GNU/Linux-libre 7.0 LTS
    - *Linux-libre is the Linux kernel with all non-free modules and firmware removed*

Respects Your Freedom

- **ThinkPenguin WiFi with Free Software Firmware!**
  - https://www.fsf.org/resources/hw/endorsement/thinkpenguin
- **TPE-NWIFIROUTER Wireless N Broadband Router**
  - pre-installed with libreCMC, an FSF-endorsed embedded GNU/Linux distribution
- **TPE-N150USB & TPE-N150USB USB Adapters**
  - Free Software firmware for Atheros AR9271
  - Linux-libre ath9k-htc kernel module